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1 **Defining patterns of sagittal standing posture in school-aged girls and boys**

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Abstract

Background. Sagittal postural patterns are associated with back pain in adolescents and adults. However, it is unknown if postural **patterns** are already observable during childhood. This would confirm childhood as a key period for posture differentiation and thus for chronic pain etiology.

Objective. We aimed to identify and describe postural patterns in school-aged girls and boys.

Design. This was a cross-sectional study.

Methods. Eligible children were evaluated at age 7 in the population-based birth cohort Generation XXI, Portugal. Posture was assessed through right-side photographs during habitual standing with retro-reflective markers placed on body landmarks. We defined postural patterns from trunk, lumbar and sway angles using model-based clusters and associations with anthropometric measures were assessed by multinomial logistic regression.

Results. Posture was evaluated in 1147 girls and 1266 boys. Three postural patterns were identified: “Sway” (26.9%), “Flat” (20.9%) and “Neutral to Hyperlordotic” (52.1%) in girls; “Sway to Neutral” (58.8%), “Flat” (36.3%) and “Hyperlordotic” (4.9%) in boys. In girls, higher body mass index was associated with a Sway pattern (vs. Flat, OR=1.21; 95% CI: 1.12-1.29), while in boys, body mass index was higher in the Hyperlordotic pattern (vs. Flat, OR=1.30; 95% CI: 1.17-1.44).

Limitations. Photogrammetry as a non-invasive method for posture assessment may have introduced some postural misclassification.

Conclusions. Postural patterns in seven-year-old children were consistent with those previously found in adults, suggesting childhood as a sensitive period for posture

1 differentiation. Sagittal morphology differed between genders, emphasizing gender-
2 specific biomechanical loads during habitual upright position even in prepubertal ages.

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4 **Word count: 3743**

1 **Introduction**

2 Established sagittal spino-pelvic alignment is associated with back pain and physical
3 disability,⁽¹⁻³⁾ with overall sagittal imbalance showing high predictive ability for
4 functional loss and dependency in older ages.⁽⁴⁾ Sagittal spino-pelvic alignment in
5 adulthood is the end result of the complex process of gaining the upright position during
6 childhood and adolescence, which stabilizes after skeletal maturity.⁽⁵⁻⁷⁾ An initial
7 verticalization of the pelvis occurs after birth, with the lordotic curve arising at the lower
8 back as the child begins to assume a sustained upright position. Then, pelvis shape and
9 physiologic curves of the spine gradually develop with growth in order to ensure an
10 adequate balance and appropriate configuration in terms of response to skeletal loads and
11 energy expenditure.⁽⁵⁻⁷⁾ For instance, a progressive increase of the lumbar angle
12 complemented with backward tilt of the spine over the hips is observed.⁽⁸⁾

13 Different classifications of sagittal phenotypes have been proposed,⁽⁹⁻¹³⁾ generally taking
14 as reference a neutral postural pattern characterized by intermediate values of alignment
15 and representing a well-balanced spine. Non-neutral sagittal postures are then
16 characterized by deviations from the neutral pattern and feature different combinations of
17 regional alignment and global balance. Since postural patterns account for the potential
18 synergistic effects of different spino-pelvic characteristics aggregated into a unique
19 phenotype, they are expected to pose an advantage for the understanding of standing
20 posture. In terms of clinical meaning, non-neutral sagittal standing postural patterns have
21 been associated with back pain in adulthood^(3, 14) and in late⁽¹⁰⁾ and early⁽¹¹⁾ adolescence.
22 However, classification of postural patterns in children has not been attempted and it is
23 unknown if the division of people into neutral and non-neutral variants occurs in the early
24 stages of life where extensive growth and development of the musculoskeletal system
25 takes place.⁽¹⁵⁾ Therefore, our hypothesis is that empirically-obtained patterns in school-

1 aged children are consistent with those observed in mid-adolescence and adulthood in
2 terms of sagittal morphology, although less differentiated patterns can be expected due to
3 the continuing development of the musculoskeletal system in children.

4 In order to study early childhood as a sensitive period for the development of sagittal
5 postural patterns, it is important to focus on prepubertal children, since they are still
6 largely homogeneous within genders with regard to sexual and skeletal development, i.e.
7 before pubertal timing begins to modulate individual posture development.⁽¹⁶⁾ Thus, we
8 aimed to identify and describe postural patterns among 7-year-old girls and boys, and to
9 explore their associations with anthropometric characteristics.

Methods

Participants

This study was conducted within the Generation XXI, a population-based birth cohort of 8647 live born infants and their mothers initially assembled from all five public maternity units covering the six municipalities of the metropolitan area of Porto, Portugal, in 2005–2006.^(17, 18) At birth, 91.4% of invited mothers agreed to participate. Invitation to the 7 years old follow-up was carried out on the basis of children's birthdate and 79.7% of those initially recruited participated in this wave of assessment. A subsample of 3005 children consecutively attending this clinic between December 2012 and August 2013 were eligible to posture assessment. (Figure 1). Potential bias was assessed by comparing included and not included Generation XXI children. The Generation XXI cohort study was approved by the Ethics Committee of São João Hospital/University of Porto Medical School and complies with the Helsinki Declaration and the current national legislation, and was also approved by the National Committee of Data Protection.

Data collection

As part of the 7-year-old evaluation, data were collected by trained interviewers in face-to-face assessments. Weight was measured to the nearest tenth of a kilogram using a digital scale (TANITA®) and height was measured to the nearest tenth of a centimeter using a wall stadiometer (SECA®). Body mass index (BMI) was computed as weight (kilograms) over squared height (meters).

Sagittal standing posture

Sagittal standing posture evaluation was performed by quantitative assessment of photographs of the sagittal right view of children, a method previously validated in adolescents⁽¹⁹⁻²¹⁾ and adults^(22, 23) and characterized by acceptable reproducibility.⁽²⁴⁻²⁶⁾ By

1 extrapolation, photogrammetry is recommended as the safest method for postural
2 evaluation in large-scale studies of children.^(13, 24, 25) This evaluation occurred between
3 March 2013 and February 2014 (median [interquartile range] of 62 [211] and 63 [212]
4 days after the 7-year-old evaluation for girls and boys, respectively). For both genders,
5 median age (25th percentile-75th percentile) was 7.3 (7.1-7.7) years.

6 Using double-faced adhesive tape, spherical retro-reflective markers (12mm and 30mm)
7 were placed over anatomical landmarks on the right-side of the child's body: lateral
8 canthus of the eye, tragus, anterior border of the acromium (30mm), spinous processes of
9 C7 and T12 (30mm), anterior superior iliac spine, greater trochanter, lateral epicondyle
10 of the femur and lateral malleolus. Additionally, a plumb line with two 20mm polystyrene
11 circumferences (50cm distance from each other) was placed behind children and 50cm
12 from the wall (the same distance as the right side of the child's body) in order to allow
13 vertical angle offset and distance calibration during the digitization of photographs.
14 Evaluation was performed by one of two health professionals in a dedicated room. Both
15 examiners received several theoretical and practical sessions of anatomy tuition before
16 data collection.

17 Children were barefoot, wearing underwear or swimwear and were instructed to rest
18 comfortably in habitual standing position with feet slightly apart, looking straight ahead
19 and moving elbows forward, as previously described in Perry et al⁽²⁴⁾ to standardize
20 position of participants. Floor markers were further used to regulate the relative position
21 of children in respect to the camera. After the examiner judged that the usual upright
22 position had been attained, full-body flash photographs were obtained using a Canon
23 PowerShot A2300 (4608 x 3456 pixels) attached to a 60cm-high tripod, placed 200cm
24 from the wall and perpendicular to the child. The tripod was fixed on the floor and the
25 zoom feature of the camera was not used.

Anatomical landmarks were then digitized using the valid and reliable postural assessment software PAS/SAPO,⁽²⁷⁾ which allowed computation of nine angles and three distances describing sagittal standing position in accordance with the protocol suggested by Perry et al.⁽²⁴⁾ This protocol prioritizes biologically relevant measurements (i.e., quantifies the relative position of body segments), avoiding the use of the vertical line reference and therefore optimizing photographic reliability.⁽²⁴⁻²⁶⁾ Angles were formed by the lines traced from the labelled anatomic landmarks and the two-dimensional coordinates of each marker were used to determine distances, as exemplified in Figure 2. All the photographs were digitized by one of the researchers who carried out the physical examinations and who is a physiotherapist (author FAA) following specific training in order to measure angles in a systematic manner in terms of order and quality. The zoom feature of the software was used freely.

Statistical analysis

Inter-observer calibration

Each child was evaluated only by one examiner, and thus, we tried to minimize the possible systematic bias between observers. Since participants were randomly allocated to each examiner, differences in distribution of measurement are attributed to observer effects.⁽²⁸⁾ Therefore, calibration considering the measurements of the physiotherapist examiner as the reference was performed, i.e., adding the difference between means obtained by each examiner to the individual values of each child evaluated by the second observer; **for this purpose called calibrated measures.**⁽²⁹⁾

Sagittal postural patterns

Trunk, lumbar and sway angles (panels F, G and H in Figure 2) completely characterize thoraco-lumbo-pelvic sagittal alignment in the standing position,⁽¹⁰⁾ corresponding to the most relevant sagittal characteristics evaluated in clinical settings,⁽³⁰⁾ and were therefore used to identify postural patterns.

The calibrated measures explained in the previous section were used to define postural patterns. Since **spinal posture differed** between girls and boys **and** seems to contribute to the unequal prevalence of **postural** deformities between genders,^(31, 32) we chose to identify patterns separately for girls and boys. Model-based clustering mclust⁽³³⁾ was then used to identify groups of children who share similar posture. This clustering procedure was chosen instead of the conventional heuristic methods because it has the key advantage of allowing testing different variances of angle measures within and across clusters. Thus, **postural angles** are assumed to have a multivariate normal distribution, parameterized by their means and covariances. The geometric features (orientation, volume and shape) of the distributions are estimated from the data, and their differences across clusters are tested.⁽³⁴⁾ **Initially the model assessed as optimal in terms of geometric features and number of clusters was determined as that with the smallest Bayesian Information Criterion (BIC).**⁽³⁵⁾ Additionally, the choice was also informed by previously identified patterns at older ages:^(9, 10) increased kyphosis with spinal backward tilt (Sway); straight spine with forward trunk lean (Flat); neutral alignment and balance (Neutral); and increased thoracic and lumbar spinal curves (Hyperlordotic). Data analysis was conducted using the software R 2.14.1.

Associations with covariates

The associations between postural clusters and weight, height **and** BMI were assessed **through** analysis of variance or Kruskal-Wallis tests. Age-adjusted odds ratios (OR) and

1 respective 95% confidence intervals (95% CI), were estimated by multinomial logistic
2 regression models **for membership of postural patterns as a function of weight, height**
3 **and BMI**. To assess the effect of weight, estimates were additionally adjusted for height.

Results

Posture was evaluated in 1147 girls and 1266 boys after exclusions and refusals. Included children were slightly older than those not included ($p < 0.001$ in both genders) and mother's formal education was higher for included children (median years: 12.0 vs. 9.0 for both genders; $p < 0.001$). Despite this, children included and not included were similar regarding anthropometric characteristics at birth (eTable 1).

Postural patterns – statistical criterion

Crude analysis showed very weak linear pairwise associations between individual **postural angles** ($|r| < 0.20$; data not shown), and thus, we chose to not consider covariance parametrizations which allowed correlations between individual **measures** within **patterns**. However, after comparing the different types of parametrizations in our postural models, the smallest Bayesian Information Criterion was found for a one-group solution for all of these parametrizations. **Therefore, using the statistical criterion alone, the cluster solution suggested posture homogeneity. Thus,** these single cluster solutions seemed inappropriate to identify a theoretically plausible cluster structure featuring expected posture variability at the population level.

Postural patterns – statistical and theoretical criteria

We chose the next best fitting models: 2- and 3-patterns solutions (with similar BIC values in girls) and 3-patterns in boys (eFigure 1 and eFigure 2). We opted for the 3-pattern model **of equal volume, equal shape, and coordinate axes orientation (assumes different variance between variables within patterns and equal variance between patterns)** in both genders **since these models showed a better BIC when compared to the models that assumed different variance between patterns. The**

selected models were characterized by an average probability of pattern assignment of 60% in girls and 73% in boys (detailed information regarding quality assignment provided on eFigure 3). Table 1 and Figure 3 show the features of the final 3-pattern solution, separately for girls and boys. Additional postural characterization is provided in eTable 2.

Girls

In girls, patterns were labeled as “Sway” (26.9%), “Flat” (20.9%) and “Neutral to Hyperlordotic” (52.1%). Type 1 was named Sway because it showed the highest trunk angle and the smallest sway angle, mean (standard deviation) of 211.1° (4.4°) and 161.2° (3.7°), respectively. **Type 2** was labeled Flat since it presented the smallest lumbar angle (275.4° [6.0°]) and the highest sway angle (167.5° [3.4°]), while type 3 was the most frequent (present in over half of the sample) and showed the smallest trunk angle and higher lumbar angle (trunk: 199.0° [4.7°]; lumbar: 284.2° [6.5°]), and thus was named “Neutral to Hyperlordotic”.

Boys

In boys, patterns were named “Sway to Neutral” (58.8%), “Flat” (36.3%) and “Hyperlordotic” (4.9%). **Type 1** in boys showed the same postural organization as in girls (trunk angle: 207.7° [5.4°]; sway angle: 162.3° [3.4°]). However, unlike in girls, this was the most prevalent pattern in the male gender (58.8%) and was therefore named as “Sway to Neutral”. **Type 2** was also labeled Flat since it too presented the smallest lumbar angle (boys: 275.8° [6.5°]) and the highest sway angle (169.3° [3.5°]). In boys, type 3 was much less frequent (4.9%) than in girls while having more extreme features: smaller trunk angle and higher lumbar angle and was therefore named “Hyperlordotic” (trunk: 194.6° [5.6°]; lumbar: 288.9° [5.2°]).

Associations with covariates

In both genders, children in the Flat pattern were lighter and shorter with a median (25th percentile-75th percentile)/mean (SD) of 23.9kg (21.5-27.0) and 122.6cm (5.4) for girls, and 24.3kg (22.1-27.2) and 123.6cm (5.2) for boys. **Girls in the Sway pattern and boys in the Hyperlordotic pattern were the heaviest (25.6 [22.6-30.4] and 26.2 [23.7-30.3], respectively);** as presented in Table 1.

Table 2 shows the adjusted associations of anthropometrics with postural patterns as dependent variable and having the Flat pattern as reference in both genders in order to improve comparability. **For girls, after adjustment for age and height, the proportional increase in odds per 1 kg increase in weight for membership of the Sway pattern was 1.13 (95% CI: 1.08-1.19) and 1.08 (95% CI: 1.03-1.12) for membership of the “Neutral to Hyperlordotic” pattern. After adjustment for age, per 1 kg/m² of BMI, OR was 1.21 (95% CI: 1.12-1.29) for membership of the Sway pattern and 1.11 (95% CI: 1.04-1.19) for membership of the “Neutral to Hyperlordotic” pattern. For boys, after adjustment for age and height, the proportional increase in odds per 1 kg increase in weight for membership of the “Sway to Neutral” pattern was 1.08 (95% CI: 1.04-1.12) and 1.17 (95% CI: 1.09-1.26) for membership of the Hyperlordotic pattern. After adjustment for age, per 1 kg/m² of BMI, OR was 1.14 (95% CI: 1.08-1.21) for membership of the “Sway to Neutral” pattern and OR was 1.30 (95% CI: 1.17-1.44) for membership of the Hyperlordotic pattern.**

Discussion

In the present study, we identified three patterns of sagittal standing posture in school-aged girls and boys that are consistent with those previously described in adults. The Flat **pattern** was observable in both genders but it showed higher relative prevalence in boys. In addition, Sway and “Neutral to Hyperlordotic” patterns were identified in girls, while “Sway to Neutral” and Hyperlordotic patterns were found in boys. In both genders, patterns differed according to anthropometric measures, which supports them as biologically plausible **types** of sagittal posture in 7-year-old children.

Our **types** 1 and 2 in both genders resemble, in their relative features, those previously described in older ages as Sway (increased kyphosis with backward tilt of the spine over the hips) and Flat (straight spine with forward trunk lean), respectively. Our type 3 in girls corresponds to the Neutral pattern (relatively increased lumbar lordosis and intermediate body sway) and to a Hyperlordotic pattern in boys (extremely increased lumbar lordosis). However, four postural patterns have been previously described in adults (age range: 18-48 years)⁽⁹⁾ and they were then suggested to be also present in adolescents between 13 and 15 years of age:⁽¹⁰⁾ Sway, Flat, Neutral and Hyperlordotic patterns. Therefore, our type 3 in girls was named “Neutral to Hyperlordotic”. **The** aggregation of these two **patterns** seems to result from a higher lumbar angle in girls (when compared to boys: 4.9°, $p \leq 0.001$). One other **type** aggregates nearly 60% of boys and two different **patterns**: type 1 which was named “Sway to Neutral”.

These findings support the hypothesis that, using statistical and theoretical criteria together, sagittal **patterns** are observable even from early childhood and it seems likely that, to some extent, they will track over time, leading to the patterns described in adolescence⁽¹⁰⁾ and adulthood.⁽⁹⁾ Our finding of a single **pattern** solution when statistical-only criteria are applied is in accordance with an initial hypothesis of less differentiated

patterns in children, where we expect a progressive maturational process of the constitutional sagittal typology due to a stronger control of sagittal balance as children get older.^(7, 26)

Longitudinal studies are required to confirm that both covariance structure and number of patterns will change over time, but this hypothesis is further supported by the direction of the relationships between the observed patterns and anthropometrics. In particular, increasing BMI from Flat to Hyperlordotic patterns, in agreement with the increasing gradient reported across the Flat, Neutral, Sway and Hyperlordotic types.^(10, 13, 36)

Furthermore, differences in body mass index across patterns in this work still hold after comparing patterns weighted by probability of **pattern** membership (data not shown). BMI is indeed the most consistent determinant of sagittal posture development,⁽¹³⁾ since adiposity is thought to cause plastic deformation of spino-pelvic structures in early ages, thus promoting tracking of specific sagittal **patterns** throughout life. Additionally, using the same statistical procedures as used among adolescents research (i.e., hierarchical analysis by Ward's method followed by the K-means algorithm)⁽¹⁰⁾ separately for each gender, the best solution was congruent with the present results (data not shown). The same postural meaning of patterns was observed, **despite the homogeneous prevalence of patterns** (varying from 30% to 37%).

In this study the “Neutral to Hyperlordotic” pattern was by far the most prevalent in girls (52.1%), and 58.8% of the boys showed a “Sway to Neutral” pattern. The most plausible reason for the clear different structure of patterns between girls and boys, seems to be a true gender heterogeneity of postural types among school-aged children. While in girls the Hyperlordotic posture was merged within the wide Neutral **type** and this seems to be driven by their similarly increased lumbar angle,^(9, 10) in boys, the Sway and Neutral types were the most similar, probably determined by a predominant backward tilt of the spine

in children⁽⁷⁾ **and observed in this study only in boys.** Differences in lumbar lordosis between genders have been incongruently reported⁽¹³⁾ but the female spine features structural phylogenetic adaptations that may justify an increased lumbar angle among girls.^(13, 31, 32, 37, 38) Concordantly, only a small group of Hyperlordotic boys (4.9%) was identified, with model-based procedures able to differentiate this pattern of high lumbar angle from all the other boys with a smaller angle at the lumbar region. Therefore, we still chose to retain this solution despite the small group of hyperlordotic boys. The Flat pattern was the only one commonly observed in both genders, but it seems to be more prevalent in boys than in girls (36.3% vs. 20.9%), as reported in adolescents^(10, 36) and adults,^(13, 39) and in agreement with the general knowledge that the male spine is less curved in the lumbar region.^(13, 31, 32, 37, 38)

Evidence of the clinical relevance of postural patterns is compelling.^(3, 9-11, 14, 40, 41) In adults, both **flat and lordotic postural types have been associated** with back pain.^(3, 14) Additionally, Sway and Flat **types** are expected to contribute to the mechanical etiology of discopathy and a Hyperlordotic **type** to vertebral listhesis.^(9, 40, 41) In mid-adolescence, all non-neutral types were associated with the presence of different measures of back pain,⁽¹⁰⁾ and in 12.6 years aged boys, a sway back balance was associated with higher prevalence of pain in the low back and neck.⁽¹¹⁾ In our sample, future follow-up of these children to assess the onset of back pain will be of great value to improve our knowledge regarding the clinical role of posture throughout life. However, it should be highlighted that one of the main findings of this work is the lack of a neutral variant of sagittal standing posture in both genders, emphasizing that we should be especially cautious in the interpretation of neutral alignment or balance as the ideal variant in school-aged children, a notion frequently implied in clinical settings.^(9, 13, 42)

1 This is the largest population-based investigation of sagittal postural patterns so far, and
2 the first to focus on school-aged children under 10 years of age. **In cluster analysis it is**
3 **recommended that sample size should be $5 \cdot 2^k$ (k = number of input variables),⁽⁴³⁾**
4 **which in this case would originate a minimum sample size of 40, meaning that our**
5 **sample size clearly provided enough power to carry out the present analysis.** Model-
6 based clustering in this study allowed us to assess the most appropriate configuration
7 among ten different solutions of covariance structures, whereas previously used⁽¹⁰⁻¹²⁾
8 heuristic clustering methods – Ward’s and K-means – consider only one restricted
9 covariance structure.⁽³³⁾

10 Conceptually, sagittal patterns are an attempt to categorize a continuum of the postural
11 spectrum. Classifying children into mutually exclusive classes may have led to some
12 misclassification, especially if children show a combined distribution of individual
13 **postural angles** that is compatible with more than one pattern. For example, children
14 classified in the Flat pattern still have a 31% average probability of being a “Neutral to
15 Hyperlordotic” type in girls and 25% of being a “Sway to Neutral” **type** in boys (eFigure
16 3). Nevertheless, our statistical approach allowed us to quantify uncertainty for each
17 pattern assignment which is particularly useful to model sagittal posture within a
18 probabilistic framework.⁽⁴⁴⁾

19 Finally, the use of photogrammetry to assess our major outcome may have introduced
20 some misclassification because of systematic or random differences in placement of
21 markers between and within examiners, which can depend on children’s anthropometric
22 characteristics, namely lower accuracy in pelvic anatomical identification in children with
23 higher subcutaneous adiposity.⁽²⁴⁾ However, these issues are not expected to compromise
24 our findings for several reasons: (1) systematic differences were accounted for by
25 quantifying children’s distance to the average values within each examiner’s distribution;

(2) consistent statistically significant associations between weight/BMI and postural types were still observable in both genders; (3) we confirmed the validity of proposed patterns against postural **measures** not used in the cluster solution **in itself and expected to vary across clusters (as shown in eTable 2). Prominent landmarks were used to obtain these postural measures, and thus**, they are not expected to be associated with the accuracy of landmark identification. This is further supported by the fact that we identified three main patterns that are clearly distinct from each other (differences varying between 6.3° to 13.1°), while random error of the measurement method is estimated to vary between 3.5° and 6.7°.⁽²⁴⁾ Additionally, sagittal posture assessment by photogrammetry is well recognized as the safest available method for postural evaluation of children.^(13, 24, 25)

We identified a meaningful summary model for the distribution of sagittal standing posture for school-aged girls and boys. Patterns were consistent with childhood as a sensitive period for posture differentiation. However, postural dichotomy “neutral vs. non-neutral” clearly does not apply to children and substantial gender heterogeneity in the features and frequency of different patterns existed among school-aged children. This highlights the potential for gender-specific biomechanical frameworks of the spino-pelvis during habitual upright position even in prepubertal ages, implying different biomechanical loads and perhaps contributing to the well-known gender differences of pediatric spinal deformities, such as **higher frequency of scoliosis in girls and Scheuermann’s disease in boys.**

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1 **Table 1.** Selected postural **measures** and anthropometrics in model-based sagittal postural patterns, separately for girls and boys.

| | Girls | | | | | Boys | | | | | Girls vs. Boys |
|---------------------------------------|-------------------------|-----------------------------------|-----------------------------------|--|--------|-------------------------|---|-----------------------------------|--|--------|----------------|
| | All | 1: Sway pattern (n=309, 26.9%) | 2: Flat pattern (n=240, 20.9%) | 3: Neutral to Hyperlordotic pattern (n=598, 52.1%) | P | All | 1: Sway to Neutral pattern (n=745, 58.8%) | 2: Flat pattern (n=459, 36.3%) | 3: Hyperlordotic pattern (n=62, 4.9%) | P | P |
| Trunk angle, ° | 203.7 (6.8) | 211.1 (4.4) | 205.9 (3.4) | 199.0 (4.7) | <0.001 | 204.8 (6.4) | 207.7 (5.4) | 201.4 (4.9) | 194.6 (5.6) | <0.001 | <0.001 |
| Lumbar angle, ° | 281.7 (7.4) | 281.9 (7.2) | 275.4 (6.0) | 284.2 (6.5) | <0.001 | 276.8 (7.2) | 276.4 (6.8) | 275.8 (6.5) | 288.9 (5.2) | <0.001 | <0.001 |
| Sway angle, ° | 164.9 (4.6) | 161.2 (3.7) | 167.5 (3.4) | 165.8 (4.2) | <0.001 | 164.8 (4.9) | 162.3 (3.4) | 169.3 (3.5) | 162.7 (4.3) | <0.001 | 0.683 |
| Weight, kg | 24.8 (22.2-28.9) | 25.6 (22.6-30.4) | 23.9 (21.5-27.0) | 24.8 (22.3-28.7) | <0.001 | 25.0 (22.6-28.2) | 25.3 (22.9-28.6) | 24.3 (22.1-27.2) | 26.2 (23.7-30.3) | <0.001 | 0.563 |
| Height, cm | 122.8 (5.1) | 123.2 (5.0) | 122.6 (5.4) | 122.7 (5.1) | 0.237 | 123.9 (5.3) | 124.1 (5.3) | 123.6 (5.2) | 124.4 (4.7) | 0.243 | <0.001 |
| Body mass index, kg/m ² | 16.49 (15.18- 18.60) | 16.89 (15.35- 19.52) | 16.03 (14.87- 17.45) | 16.55 (15.28-18.62) | <0.001 | 16.30 (15.25- 17.77) | 16.41 (15.35- 17.99) | 15.90 (14.94- 17.01) | 17.36 (15.75-19.35) | <0.001 | 0.018 |

2 Values are reported as mean (standard deviation), median (25th percentile-75th percentile), or n (%).

3 Two girls and one boy have missing information for anthropometric measures.

4

Table 2. Adjusted associations between model-based postural patterns (dependent variable) and anthropometrics (independent variables), separately for girls and boys.

| | Sway pattern | | | Flat pattern | Neutral to Hyperlordotic pattern | | | P [†] |
|------------------------------------|-------------------------|-------------|--------|--------------|----------------------------------|-----------|--------|------------------|
| | OR* | 95% CI | P | OR | OR* | 95% CI | P | |
| | | | | | | | | |
| Girls | | | | | | | | |
| Weight, kg | 1.13 | 1.08-1.19 | <0.001 | 1 | 1.08 | 1.03-1.12 | 0.001 | <0.001 |
| Height, cm | 1.03 | 1.00-1.07 | 0.067 | 1 | 1.01 | 0.98-1.04 | 0.489 | 0.011 |
| Body mass index, kg/m ² | 1.21 | 1.12-1.29 | <0.001 | 1 | 1.11 | 1.04-1.19 | 0.001 | <0.001 |
| | Sway to Neutral pattern | | | Flat pattern | Hyperlordotic pattern | | | P |
| | OR* | 95% CI | P | OR | OR* | 95% CI | P | |
| | | | | | | | | |
| Boys | | | | | | | | |
| Weight, kg | 1.08 | 1.04-1.12 | <0.001 | 1 | 1.17 | 1.09-1.26 | <0.001 | <0.001 |
| Height, cm | 1.02 | 1.0009-1.05 | 0.042 | 1 | 1.04 | 0.98-1.09 | 0.179 | <0.001 |
| Body mass index, kg/m ² | 1.14 | 1.08-1.21 | <0.001 | 1 | 1.30 | 1.17-1.44 | <0.001 | <0.001 |

OR, odds ratio; CI, confidence interval.

* All variables adjusted for age; Weight additionally adjusted for height.

[†]Overall test of differences in odds across the 3 groups.

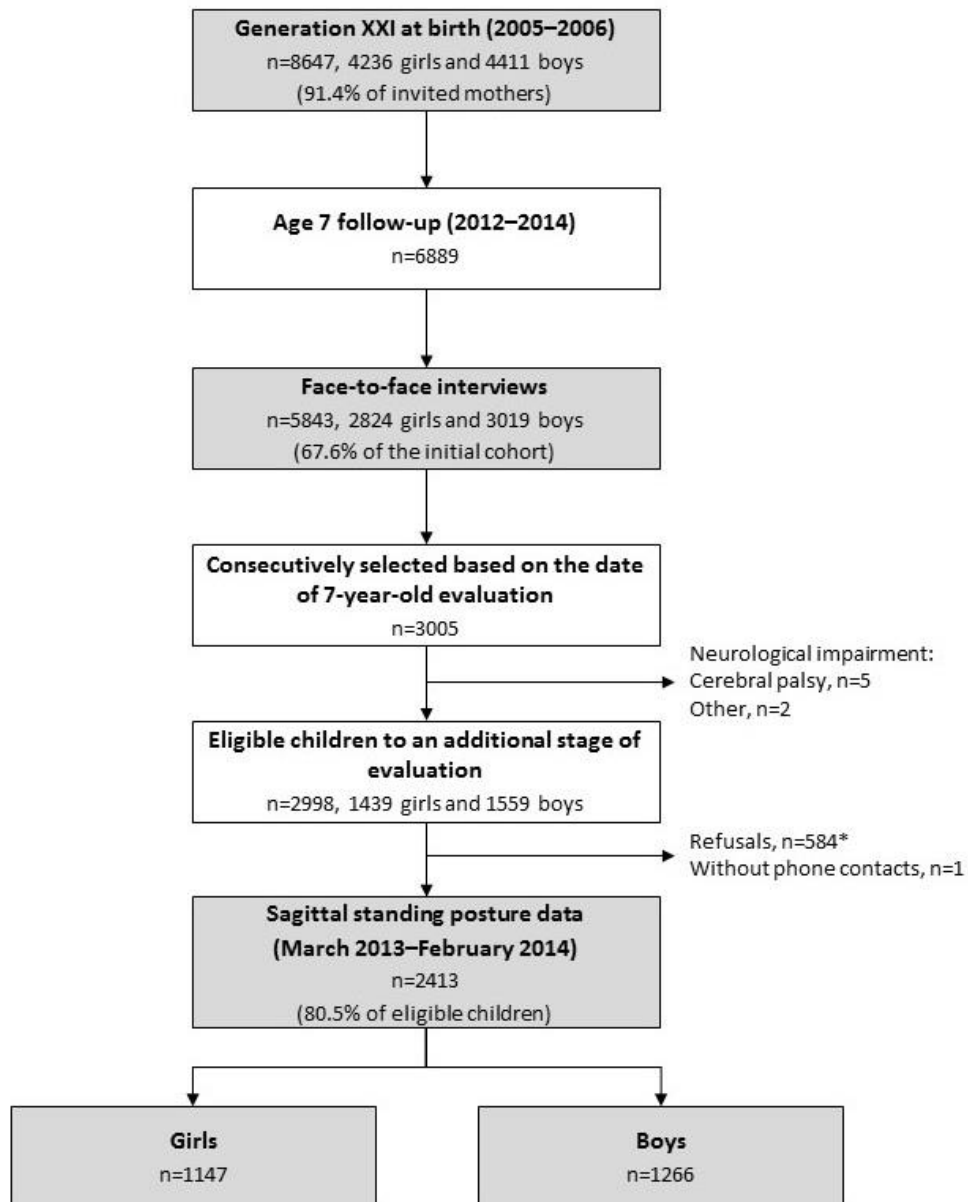
Comparisons between Sway and “Neutral to Hyperlordotic” patterns (in girls) and between “Sway to Neutral” and Hyperlordotic patterns (in boys) reach statistical significance (p<0.05) in weight and body mass index.

Two girls and one boy have missing information for anthropometric measures.

Figure 1. Flow diagram of Generation XXI children inclusion.

Figure 2. Definition of angles (A-I) and distances (J-L) describing sagittal standing posture: (A) Head flexion; (B) Neck flexion; (C) Craniocervical angle; (D) Cervicothoracic angle; (E) Thoracic flexion; (F) Trunk angle; (G) Lumbar angle; (H) Sway angle; (I) Pelvic tilt; (J) Head displacement; (K) Scapular elevation; (L) Scapular displacement. Dashed lines indicate the vertical or horizontal. Delimited angles (F, G and H) were used in model-based patterns of sagittal standing posture.

Figure 3. Box plots showing the distribution (median, inter-quartile range and range) for each individual postural **measure**, standardized to have a mean of zero and standard deviation of one, across model-based sagittal standing postural patterns (left panel) and typical members within each pattern (right panel), shown separately for girls and boys.



*Participants who refused to participate in the posture evaluation (n=252), or scheduled three different appointments but did not show up for evaluation, or did not respond to our invitation after at least five attempts (n=332).

Figure 1.

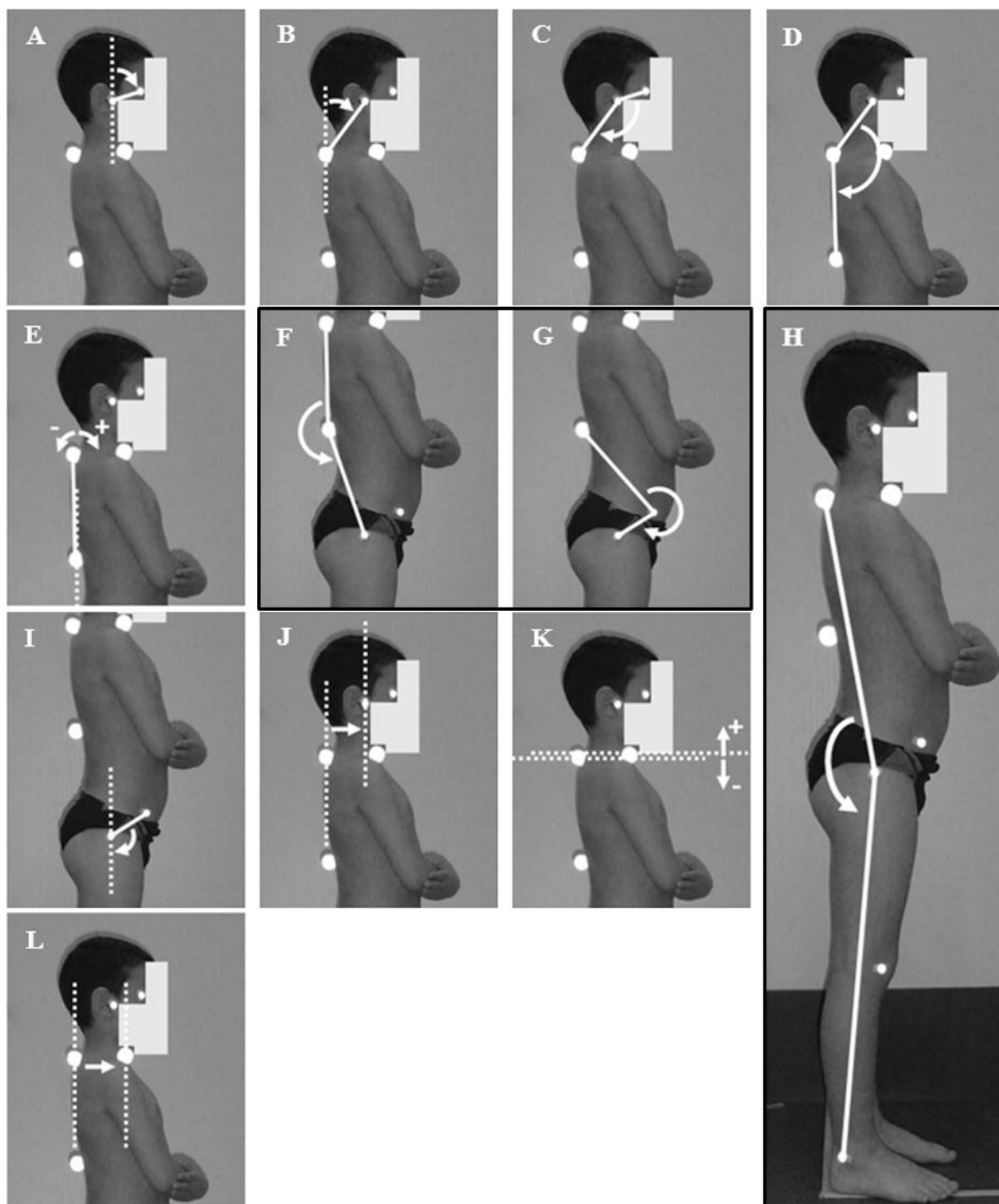


Figure 2.

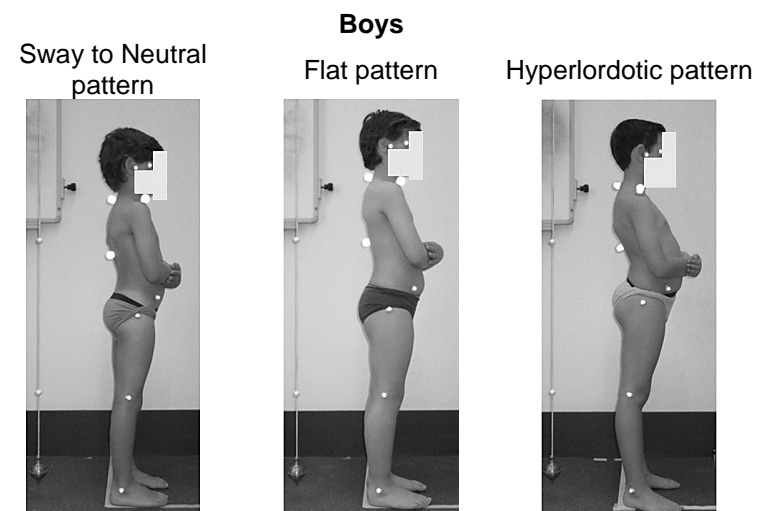
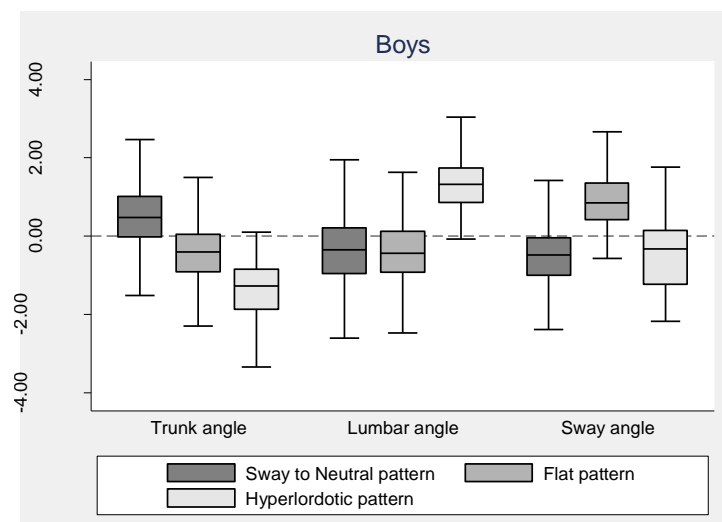
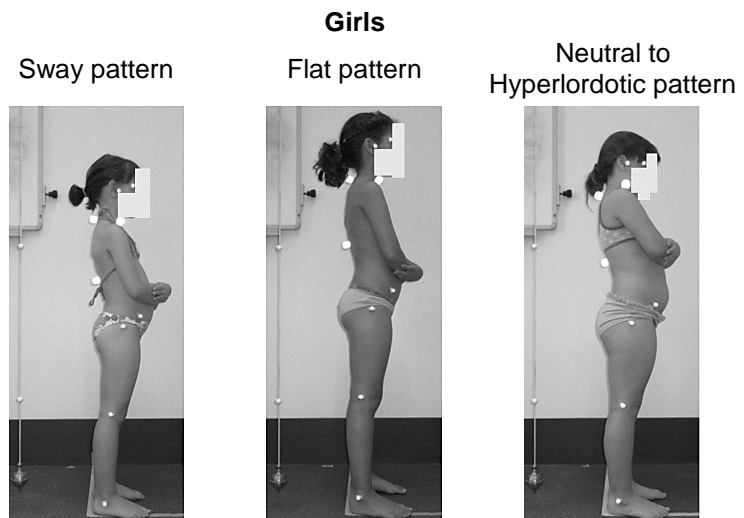
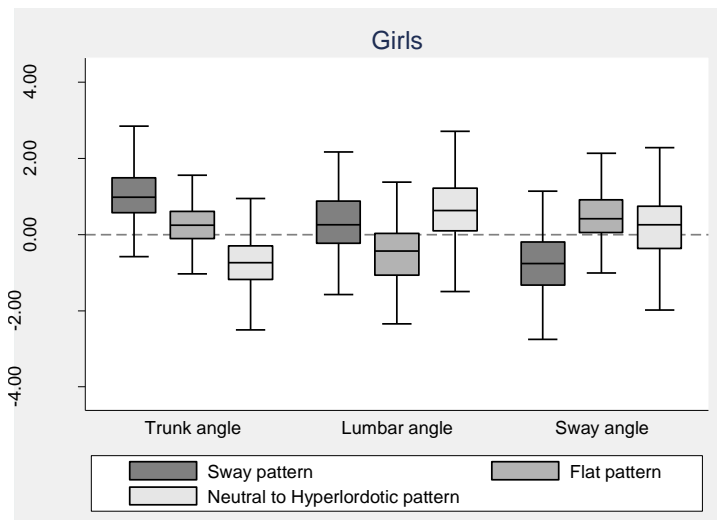


Figure 3.